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## The pretreatment of turbid surface water prior to slow sand filtration

There are several important advantages in the employment of slow sand filtration, for the treatment of potable water supplies in the developing world which include simplicity of design, the possibility of using local materials in the construction, the relatively low technical level required for operation and, particularly, the high bacteriological quality of the produced filtrate. There is however, one important drawback that has inhibited the wider adoption of this process and that is the difficulty which occurs when attempting to continually filter water of a high turbidity. High turbidities of the raw waters fed to slow sand filters result in short filtration runs and necessitate frequent cleaning which adds appreciably to the problems and cost of operation as well as requiring larger installed filter surfaces.

Maximum turbidities in the raw water, over prolonged periods, of between 10 and 50 turbidity units<sup>1</sup> have been quoted although it is normally accepted that higher turbidities of perhaps 50 T.U. to 120 T.U. can be tolerated for one or two days without major increases in the head-loss<sup>1</sup>. Throughout much of the tropical world surface waters have very high turbidities during at least part of the year which corresponds with the rainy, or monsoon season. This, again, is a major reason that slow sand filters have not been more widely adopted in regions where, apart from the difficulties of high turbidities, they could be most advantageously employed.

### AVAILABLE TECHNIQUES FOR TURBIDITY REDUCTION

Techniques are available for the pre-treatment of highly turbid raw water to bring down the initial turbidity to a level suitable for continual slow filtration (less than 30 T.U.). These available techniques can be listed as:

- Infiltration wells and galleries
- Storage
- Plain sedimentation
- Rapid roughing filters (vertical flow)
- Horizontal-flow gravel filters
- Chemical pre-treatment
- Rapid sand filters (gravity, upflow, pressure)
- Coarse filtration at the river bed

### INFILTRATION WELLS AND GALLERIES

Infiltration wells and galleries are employed widely in the Indian sub-continent and occasionally in other parts of the world. They can be extremely effective either for the partial treatment of high-turbidity waters or for the total treatment of less turbid waters. Large diameter shallow wells situated on the river bank may be employed so that the water abstracted from the river must percolate through the silt of the river bottom and the gravel of the river bed to reach the well from which it may then be pumped directly to the slow sand filters. More sophisticated arrangements have infiltration galleries running from the river-side well. These may be laid either in the bank, parallel to the flow, or under the river.

### CHEMICAL PRE-TREATMENT

Chemical pre-treatment for the coagulation and flocculation of finely divided suspended material, followed by sedimentation, may be employed prior to slow sand filtration in a manner identical to that operated prior to rapid gravity sand filtration. This is effective but removes, for much of the world, two of the major advantages of slow sand filtration - those of simplicity and low operational costs.

### PLAIN SEDIMENTATION

Plain sedimentation prior to slow sand filters has been attempted but it is only of appreciable efficacy if the suspended solids to be removed from the feed water are of sufficient size to settle readily within a few hours.

### LONG PERIOD STORAGE

The long term storage of water prior to filtration can bring about a major improvement in water quality. This is practiced in many places and notably in London. Over a long period all the readily settleable material is removed. There is also some coalescing and settlement of finer suspended materials. In addition a continuing degradation of biodegradable organic material occurs and, importantly, there is a major die-off of potentially harmful microorganisms. Long term storage is used for this purpose on a village scale in several locations in Thailand<sup>2</sup>. There

is however, a disadvantage associated with the technique and that is the potential, particularly in hot countries, for blooms of algae to occur.

#### COARSE-MEDIA GRAVITY FILTERS

Coarse-media gravity filters have been suggested<sup>3,4</sup> as pre-treatment techniques for slow filtration. The medium employed is normally rock or pebbles. Coarse filtration in the river bed at the point of abstraction has also been used. This filter may be in the form of a basket of pebbles through which the water must be extracted. For a shallow stream a more reliable method may be to lay a perforated abstraction pipe on the river bed, across the flow, and just on the upstream side of a low weir. This pipe is then covered with gravel on which the stream itself deposits a layer of silt. The abstracted water must then be pulled through both a layer of silt and a depth of gravel. This will reduce effectively the initial turbidity. The gravel/silt pre-filter is held in position by the weir and the flow of the stream continually washes off the top layer of silt and replaces it with fresh material.

#### RAPID SAND FILTRATION

For larger more sophisticated situations where there are turbidity problems with the raw water, conventional rapid sand filtration has been effectively employed<sup>5</sup>. The rapid sand filters can be either conventional gravity filters or upflow sand filters or even pressure-filters. They are normally operated without chemical pre-treatment. All these techniques are widely employed in the UK where rapid gravity filters are installed prior to slow sand filters at several sites.

#### HORIZONTAL-FLOW GRAVEL FILTRATION

The use of horizontal flow gravel filtration as a pre-treatment technique prior to slow sand filters is not a new technique. It was employed for many decades at the old Fobney treatment in England. It has also been used in Germany<sup>6</sup>.

Some German gravel pre-filters are quite sizeable, being between 50 m and 70 m long, and filled with 0.4 m depth of 5-12 mm gravel on top of a layer of 30-70 mm gravel. The flow rate is 10 m/h to 20 m/h<sup>4,7</sup>. The suspended solids content of the river water rises to 270 mg/l in spate conditions and can be reduced through the horizontal filter by 75%, but to achieve this the treatment rate has to be dropped to 8 m/h.

A complete run with these German filters is expected to take between five and six years because of the very high storage capacity for

removed silt. Certainly at Aesch (Switzerland), where the horizontal flow gravel filter of 15 m length operated at an average rate of 5 m/h (8 m/h maximum), it had not been cleaned for four years and the following slow sand filter had not been cleaned for three years.

#### INVESTIGATIONAL WORK IN THAILAND

Much work has been carried out in Thailand at the Asian Institute of Technology into the operation of horizontal-flow gravel filters. Initially the work was carried out on a laboratory scale. The laboratory-scale model was 1.2 m long with four consecutive 300 mm compartments containing 9.1 mm crushed stone, 6.4 mm, 2.8 mm and finally 9.1 mm<sup>8</sup>. The rate of treatment was 14.4 m/day and the raw water employed for both laboratory-scale and pilot-scale investigations varied normally between 24 to 50 JTU although this increased to as high as 114 JTU during rainy periods. On average the turbidity was reduced by between 60% to 64% and, interestingly, this was accompanied by a 70% to 75% removal of coliform bacteria for an inlet water count which varied between 1100 and 2400/100 ml.

Following the laboratory-scale work at the AIT, a pilot-scale horizontal-filter 6 m long by 1.5 m wide by 1.0 m deep was constructed<sup>8</sup> and filled with vertical layers of 15.7 mm, 6.8 mm, 4.5 mm, 3.5 mm, 3.4 mm, 4.5 mm and 15.7 mm crushed stone which was again operated at 14.4 m/d. The removal of turbidity was 63% following an early maturation period of 20 days. It was perhaps strange that a maturation period was necessary for a process in which, it would be expected, most of the turbidity removal was brought about by sedimentation.

#### RESEARCH IN TANZANIA

Early experiments<sup>9,10</sup> carried out on a small scale demonstrated that smaller aggregates in horizontal flow pre-filters were superior to larger aggregates. These experiments also demonstrated that turbidity removals declined markedly at flow-rates greater than 2 m/h.

The later work by the University of Dar es Salaam<sup>9</sup> was carried out at village sites. One of the pre-filters, 9 m long, consisted of three compartments in series containing, in the first, 16 mm to 32 mm gravel then 8 mm to 16 mm gravel and in the last 4 mm to 8 mm gravel. Using this pre-filter the turbidity was reduced from 115 NTU to 30 NTU at a flow rate of 0.5 m/h. from 48 NTU to 10 NTU at 0.75 m/h and from 38 NTU to 17 NTU at 1.5 m/h. The reference slow sand filter (Effective Size 0.24 mm) for this stage of the investigation, receiving water which had not been pre-filtered, blocked after three

days of operation at a rate of 0.2 m/h while the slow sand filter receiving pre-filtered water and operating at the very appreciable rate of 0.4 m/h continued for seven days. A longer pre-filter containing four 4 m compartments in series, with 16-32 mm gravel in the first, 8 mm to 16 mm in the second, 4 mm to 8 mm in the third and 2 mm to 4 mm in the fourth, was able to reduce the inlet water turbidity from 92 NTU to 39 NTU at a flow rate of 0.5 m/h and from 69 NTU to 34 NTU at a flow rate of 1.0 m/h.

#### RESEARCH IN THE UK AND PERU

Further investigation into the operation of horizontal-flow pre-filters were carried out at the University of Surrey <sup>11</sup>. These involved three filters each, 2.5 m long by 0.3 m by 0.3 m one of which contained 10 mm graded gravel, another 20 mm graded gravel, and the third 40 mm graded gravel. When the filters were operated in parallel at flow rates of between 0.5 m/h and 2.0 m/h it was found that performance was consistently inversely proportional to gravel size, with the 10 mm gravel filter removing up to 90% of the faecal coliforms and up to 75% of the turbidity. Collaborative work by the Panamericano de Ingenieria y Ciencias de Ambiente (CEPHIS-PAH of WHO) demonstrated that larger gravel is more useful for reducing gross suspended solids when influent turbidities were in the range of 200 to 2000 NTU. Further investigations by the Surrey team with the three filters in series in the order 40 mm gravel then 20 mm and then 10 mm, with influent water turbidities of only between 2 NTU and 20 NTU, achieved a removal of faecal coliforms of up to 96% and a turbidity removal of between 60% and 75%. Long term improvements in filter operation were also observed. This indicated again the need for an appreciable maturation period before full efficiency is achieved and confirmed the similar findings in Thailand and Tanzania.

#### RECENT WORK IN SWITZERLAND

The results from various investigations carried out into the operation of horizontal-flow gravel filters have certainly been encouraging but until recently it could not be accepted that adequate guidelines for design had been evolved. The work carried out by Dr Bolter at the EAWAG laboratories in Switzerland <sup>12</sup> has now, however, carried the work forward considerably.

During this research, which was carried out using suspensions of kaolin in water, a number of parameters were investigated including size and type of filter media, filter length, filtration rates, filter loading, filter efficiencies and headlosses. The variation of filter efficiency (per unit

filter length) with particle size of the suspended kaolin, filter grain size and filtration rate (m/h) was demonstrated. A semi-empirical filtration model was then developed for horizontal-flow filters in which the effluent quality and final filter resistance are the two main criteria. The actual reduction of suspended solids in the water passing through the filter is described in terms of filter efficiency as a function of rate of filtration, type of suspension, filter loading and sizes of the filter media. This filtration model can be employed to simulate horizontal-flow operations.

This investigation also revealed that as the solids are removed by gravity settling they form loose agglomerates of several mm height on top of the media grains. The height and shape of these agglomerates depend upon their slope stability and, once this is exceeded, the deposited material moves downwards within coarse media but the movement is prevented if the medium is smaller than 4 mm. This gradual downward movement restores the retention capacity of the upper regions of the filter medium and helps maintain the filtration efficiency long into the run. It also leads, obviously, to the collection of the removed solids at the filter bottom and enhances the effect of filter drainage in restoring removal capacity.

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